REPORT ON THE 2006
ROBOTICS AND INTELLIGENT
SYSTEMS PLANNING FORUM

INTERNATIONAL ADVANCED
ROBOTICS PROGRAMME

Orlando, Florida

May 14-15, 2006

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EXECUTIVE SUMMARY

Since its inception in 1982 as part of the Versailles Economic Summit, the International Advanced Robotics Programme (IARP) seeks to "To encourage development of advanced robotic systems that can dispense with human work for difficult activities in harsh, demanding, or dangerous environments." The primary platform for this role occurs in special international technical workshops held by host countries. To assist in the planning of future workshops, the IARP oversight body, the Joint Coordinating Forum (JCF), sponsored a planning forum that was held in Orlando, Florida on May 14-15, 2006. Robotics and intelligent systems experts from fourteen countries attended the Planning Forum. The participants were divided into the following working groups:

1. Medical and rehabilitation Robotics + Emerging technologies
2. Robotics in extreme environments + Action and manipulation
3. Service Robotics + Intelligence & cognition
4. Human/robot interaction & cooperation + Perception & sensing

The working groups produced 21 preliminary proposals for future IARP workshops, all of which contain valuable guidance useful for future planning. An evaluation process identified the three areas of particularly strong interest:

1. Neurorobotics for Rehabilitation, Prosthetics, and Orthotics
2. Shared Control for Robots in Hazardous Environments
3. Sensor-Based Manipulation

The Planning Forum resulted in the following conclusions and recommendations for the JCF:

1. Each and every future workshop proposal contains valuable planning information.
2. The evaluation results should only be used to consider near-term priorities and not eliminate topical areas.
3. The planning forum final report, which includes the detailed outline proposals, should be disseminated as widely as possible, especially to IARP working groups.

4. There appear to be opportunities to combine some of the workshop proposals into single workshops that would have wider interest and impact.
5. The planning forum process and associated interactions were as important as the specific proposal results. The JCF should consider holding planning forums of this nature on a regular basis, perhaps every three years.

INTRODUCTION

Numerous countries have been participating in the International Advanced Robotics Programme since its inception in 1982 as part of the Versailles Economic Summit. The general objective of the IARP is: "To encourage development of advanced robotic systems that can dispense with human work for difficult activities in harsh, demanding, or dangerous environments."

IARP meeting and workshops have provided unique and rich environments for interaction between representatives currently from over 16 nations and organizations regarding emerging technologies and key pressing problems. The IARP exchange environment is unique in its global perspective and the communication effectiveness deriving from it comparatively small size and selective participation.

In 1998 the IARP devoted a meeting to strategic planning of future workshop activities. During the June 2005 IARP meeting in Nagoya, delegates felt that the planning process associated with annual IARP workshops could be strengthened with more of a top-down approach as was done in 1998.

This report discusses the results of a special IARP Planning Forum[1] to identify potential future workshops topics for the next 3-5 years. The forum involved participation of established experts from numerous countries and was held in conjunction with the IEEE Robotics and Automation Society's 2006 IEEE International Conference on Robotics and Automation (ICRA 2006) held in Orlando, Florida, USA on May 14 and 15, 2006.

PLANNING FORUM STRUCTURE

Purpose

The purpose of the Planning Forum was to develop recommendations for the topical foci of future IARP workshops that would reflect the current state of research around the world. It was anticipated that these results would provide input to the IARP oversight body, the Joint Coordinating Forum (JCF), for use in workshop planning for the next three to five years.

Organization

The Planning Forum Organizing Committee membership is shown below.

William R. Hamel University of Tennessee	Forum Chair
Michael Reischmann National Science Foundation	JCF - USA
Norman Caplan National Science Foundation	President - IARP
Georges Giralt CNRS-LAAS	JCF - France
T. J. Tarn Washington University	Technical Advisor - USA

Forum attendance was by invitation and the list of attendees is given in Appendix I. Attendees were either JCF members or invitees from various countries who were selected based on their technical expertise.

The Planning Forum incorporated a workshop-style environment to facilitate discussion about new ideas and emerging technologies. The ICRA venue expanded access to world experts in basic robotics/intelligent systems technical areas corresponding to IARP interests.

The forum was organized around a two-day schedule (Refer to Appendix II) and was based on a structure of plenary sessions with invited speakers selected to stimulate thinking and discussion on key topics. These plenary sessions occurred on the first halves of each day. Breakout groups in selected topical areas (See Appendix III) met during the second halves of each day. The last half of the second day was devoted to presentation of breakout reports and a final report-

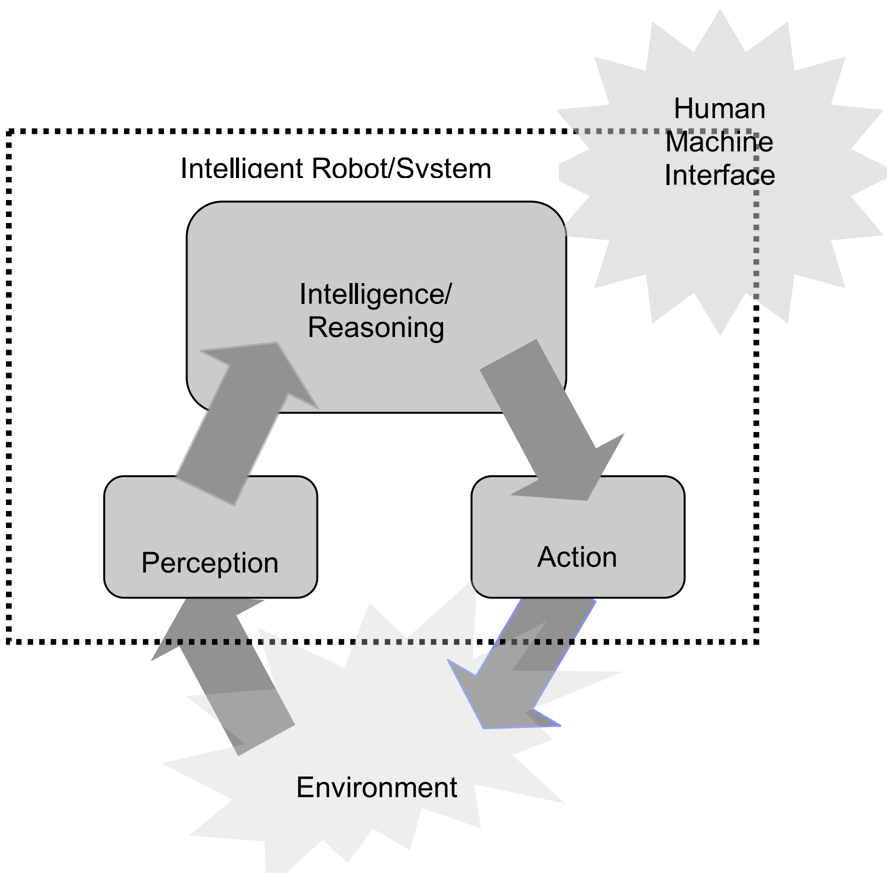

Figure 1, Technical Paradigm

out plenary session.

Plenary speakers were invited in the basic areas associated with the intelligent systems paradigm shown schematically in Figure 1. The elements of the paradigm specifically included: 1) intelligence/reasoning: cognition, machine learning, 2) perception: sensing, 3) action: manipulation, mobility, 4) human-machine interfaces including brain-computer interfacing. Micro and nano electromechanical systems were also included because of their importance as emerging technologies. The presentations given by the plenary speakers can be downloaded from the IARP website at http://www.iarp-robotics.org/.

Eight topical areas, selected by the organizing committee prior to the meeting, were used to subdivide the attendees into breakout groups where detailed discussions and planning would occur. Each breakout group was given two topical areas, one of an application-specific nature and one of a broad-technology nature. The group designations were:

1. Medical and Rehabilitation Robotics + Emerging Technologies
2. Robotics in Extreme Environments + Action and Manipulation
3. Service Robotics + Intelligence & Cognition
4. Human/Robot Interaction & Cooperation + Perception & Sensing

Breakout groups were given the following guidance for the development of specific future workshop proposals:

1. Each Breakout Group has two areas in which new workshop ideas/proposals can be considered.
2. The time horizon for the planning process is **3 to 5 years**.
3. The overall objective is to identify **specific potential workshops** the IARP Joint Coordinating Forum (JCF) may consider for their future agenda.
4. For **each specific potential workshop topic**, the breakout group should try to capture supporting information that will allow the JCF to prioritize and establish the roadmap for future workshops.

a) Identify the primary issues that motivates the topic, e.g., a workshop on energetics is needed to address the inadequacies of current electrochemical storage methods.

b) Identify the key research challenges that are embedded or associated with the primary issues.

c) Discuss the potential benefits of successful research with respect to key research challenges.

d) Define workshop implementation recommendations:

   i. Estimated scope of the workshop.

   ii. Target community; from where should participants be solicited.

RESULTS

Future Workshop Proposals Generated

The breakout groups generated a total of 21 extremely interesting outline proposals for future workshops. The titles of these proposals are given below.

Group 1, Medical and Rehabilitation Robotics + Emerging Technologies
- Proposed Workshop 1, Biomechanical Tissue Modeling for Robot-Assisted Surgery and Simulation
- Proposed Workshop 2, Safety and Quality in Biomedical Robotics
- Proposed Workshop 3, NeuroRobotics for Rehabilitation, Prosthetics, and Orthotics
- Proposed Workshop 4, Bio-Inspired Design for Milli/Micro/Nano Robotics
- Proposed Workshop 5, Micro/Nano Robot Architectures

Group 2, Robotics in Extreme Environments + Action & Manipulation
- Proposed Workshop 6, Shared Control for Robots in Hazardous Environments
- Proposed Workshop 7, Robot Energetics
- Proposed Workshop 8, Robotic Improvised Explosive Devices (IED) Detection
- Proposed Workshop 9, Mission Driven Reliable Robot Design

Group 3, Service Robotics + Intelligence & Cognition
- Proposed Workshop 10, Robot Learning Systems
- Proposed Workshop 11, Human-Robot-Human (HRH) Interaction: Tools for Rehabilitation and Training
- Proposed Workshop 12, Self-Organizing Systems
- Proposed Workshop 13, Cognitive Robot Architectures
- Proposed Workshop 14, Complex Robot Interaction with the Real World
- Proposed Workshop 15, Ambient and Embedded Intelligence
- Proposed Workshop 16, Social & Personal Robots

Group 4, Human-Robot Interaction/Cooperation + Perception & Sensing,
- Proposed Workshop 17, Human/Robot Interfacing at Neural Level
- Proposed Workshop 18, Robot-Assisted Living

Proposed Workshop 19, Human-Robot-Environment Integration
Proposed Workshop 20, Sensor-Based Manipulation
Proposed Workshop 21, Haptics - Modeling, Sensing, Display

WORKING GROUP #1 captured several excellent general ideas for future workshops that should be considered by the JCF. These are:

1. Some alternatives to the usual:
   - Two-four week institute (like Telluride neuromorphic engineering workshop). People bring their labs. Develop new projects and work on them.
   - Include training component plus summer school for students.
   - End goal of the workshop is to create a new graduate-level course on X. Also, write a textbook.
2. Possible workshop goals:
   - Summarize/synthesize existing work.
   - Identify barriers to research progress.
   - Train new researchers (invite students to some aspects).
   - Solve barriers (work together to identify specific solutions).

The proposal outlines are given in Appendix IV.

Self Evaluation of the Proposed Workshops

After the meeting in Orlando, each of the attendees was asked to evaluate the future workshop proposals by designating what they considered the five most beneficial and five least beneficial proposals. Eighteen attendees submitted their evaluations and the results are shown in Figure 2. This type of evaluation is a influenced by individual perspectives and interests. Nonetheless, the results provide useful conclusions regarding several proposals. The "voting" shows that a consensus considers the following proposals the **most beneficial**:

Proposed Workshop 3, NeuroRobotics for Rehabilitation, Prosthetics, and Orthotics

Proposed Workshop 6, Shared Control for Robots in Hazardous Environments
Proposed Workshop 20, Sensor-Based Manipulation

On the other side, the voting shows that a consensus questions the importance of the following proposals by declaring them the **least beneficial**:

Proposed Workshop 2, Safety and Quality in Biomedical Robotics
Proposed Workshop 4, Bio-inspired design for Milli/Micro/Nano Robotics
Proposed Workshop 8, Robotic IED Detection
Proposed Workshop 9, Mission Driven Reliable Robot Design
Proposed Workshop 15, Ambient and Embedded Intelligence
Proposed Workshop 16, Social & Personal Robots

Several proposals received evaluations that are inconclusive because they received comparatively large amounts of both "most beneficial" and "least beneficial" votes. The proposals with more than five and **split votes** are:

Proposed Workshop 5, Micro/Nano Robot Architectures
Proposed Workshop 7, Robot Energetics
Proposed Workshop 18, Robot-Assisted Living

Several attendees discussed the existence of overlaps in the scopes of several of the future workshop proposals. It was specifically recommended that combinations of proposal 14 with 20, and 16 with 18 should be considered. As shown in the highlighted rows of Figure 2, the potential benefits of combining these proposals was approximated by combining the individual self evaluation results. The combination of 14 and 20 (Complex interaction with the real world and sensor-based manipulation) comes out clearly as most beneficial. The combination of 16 and 18 produces a large split vote.

RECOMMENDATIONS

Each and every one of the workshop proposals contains valuable information that the JCF should consider carefully in the years ahead as they plan new workshops. The self-evaluations results should not be used to eliminate potential future workshop topics, but give a sense of priority.

The final report should be disseminated as widely as possible and specifically to members of the active working groups. A number of the proposed workshops correlate with interests of both the Demining and Robot Dependability Working Groups of the JCF.

It is recommend that the self-evaluation results only be used to guide near-term priorities and decisions. It is not surprising that neurorobotics appears in the most beneficial category. It may be surprising to some that matters of shared control and sensor-based control of manipulation in complex environments also appears in this category. These results reflect the fact there are many unsolved challenges in these areas yet today. Many of those participating in the self-evaluation process come from the research side of robotics and intelligent systems. This may explain why some workshop proposals of obvious import were ranked as least beneficial. For example, Proposed Workshop 2 addressed the extremely critical technical matters of safety and quality in biomedical robots and yet it received no most beneficial votes.

There may be innovative ways to combine workshop proposals to increase interest and participation. For example, a workshop that focuses on shared control research in the context of neurorobotics would be of interest to bio-roboticists as well as researchers working in shared control problems in other domains. There is little doubt that many other combinations can be derived from the forum results.

The process of the planning forum and the associated interactions may vary well be as important at the detailed results themselves. Most participants left the meeting with a sense that many important issues and other important workshop ideas had not been fully pursued. The JCF should consider have these planning type meetings on a regular basis, perhaps every three years.

Breakout Groups & Workshop Proposals	Self Evaluations	
	Most Benefical	Least Benefical
Group 1, Medical and Rehabilitation Robotics, and Emerging Technologies		
Proposed Workshop 1, Biomechanical tissue modeling for robot-assisted surgery and simulation	M M M M M M	L L L
Proposed Workshop 2, Safety and quality in biomedical robotics		L L L
Proposed Workshop 3, NeuroRobotics for Rehabilition, Prosthetics, and Orthotics	M M M M M M M	
Proposed Workshop 4, Bio-inspired design for milli/micro/nano robotics	M	L L L
Proposed Workshop 5, Micro/Nano Robot Architectures	M M M M	L L L
Group 2, Robotics in Extreme Environments, and Action and Manipulation		
Proposed Workshop 6, Shared Control for robots in hazardous environments	M M M M M M M M	
Proposed Workshop 7, Robot Energetics	M M M	L L L L
Proposed Workshop 8, Robotic IED detection		L L L L L L
Proposed Workshop 9, Mission Driven Reliable Robot Design	M	L L L L L L
Group 3, Service Robotics, and Intelligence and Cognition		
Proposed Workshop 10, Robot Learning Systems	M M	L L
Proposed Workshop 11, Human-Robot-Human (HRH) Interaction: Tools for Rehabilitation and Training	M	L
Proposed Workshop 12, Self-Organizing Systems	M M M	L L
Proposed Workshop 13, Cognitive Robot Architectures	M	L L L
Proposed Workshop 14, Complex robot interaction with the real world	M M M	L L
Combined 14 and 20	M M M M M M M M M	L L L L
Proposed Workshop 15, Ambient and Embedded Intelligence	M	L L L L
Proposed Workshop 16, Social & Personal Robots	M	L L L
Group 4, Perception and Sensing, and Human-Robot Interaction/Cooperation		
Proposed Workshop 17, Human/Robot Interfacing at Neural Level	M	L L
Proposed Workshop 18, Robot-Assisted Living	M M M M M M	L L L L L
Combined 16 and 18	M M M M M M M	L L L L L L L L
Proposed Workshop 19, Human-Robot-Environment Integration		L
Proposed Workshop 20, Sensor-Based Manipulation	M M M M M M	L L
Proposed Workshop 21, Haptics - Modeling, Sensing, Display	M M	

Figure 2, Self Evaluation Results

APPENDICES

APPENDIX I, LIST OF ATTENDEES

Attendee	Institution/Company	Country
Allison Okamura	Johns Hopkins University	USA
Antonio Bicchi	University of Pisa	Italy
Bill Hamel	University of Tennessee	USA
Dick Volz	Texas A&M	USA
Garie Fordyce	National Science Foundation	USA
Geoff Pegman	RURobots	UK
George Bekey	USC	USA
Georges Giralt	LAAS-CNRS	France
Greg Hager	Johns Hopkins University	USA
Kevin Lynch	Northwestern University	USA
Lynne Parker	University of Tennessee	USA
Manuel Armada	Instituto de Automatica Industrial	Spain
Michael Pardowitz	University of Karlshrue	Germany
Mike Reischman	National Science Foundation	USA
Mun Sang Kim	KIST	Korea
Ning Xi	Michigan State University	USA
Norman Caplan	National Science Foundation	USA
Ousamma Khatib	Stanford University	USA
Philippe Bidaud	University of Paris 6	France
Raja Chatilla	LAAS-CNRS	France
Russ Taylor	Johns Hopkins University	USA
Shigeki Sugano	Waseda University	Japan
Sukan Lee	Sungkyunkwan University	Korea
T.J. Tarn	Washington University	USA
Ted Berger	USC	USA
Toshi Fukuda	Nagoya University	Japan
Valery Gradetsky	Institute for Problems in Mechanics Russian Academy of Sciences	Russia
Vijay Kumar	University of Pennslyvania	USA
Wayne Book	Georgia Tech	USA
Brad Nelson	ETH-Zurich	Switzerland
Darwin Caldwell	University of Salford	UK
Fernando Lizarralde	COPPE/Federal University of Rio de Janeiro	Brazil
Claudio Moriconi	ENEA	Italy
Steffen Knoop	University of Karlshrue	Germany

APPENDIX II, PLANNING FORUM PROGRAM

2006 IARP Robotics and Intelligent Systems

Planning Forum Program

Hilton in the Walt Disney World Resort

Crystal Room

Day 1, May 14, 2006 (Sunday)

Continental Breakfast	*0730 – 0800*
Welcome	
Dr. Michael Reischman, Deputy Assistant Director Engineering Directorate, National Science Foundation	0800 – 0810
Dr. Norman Caplan, President The International Advanced Robotics Programme	0810 – 0820
Agenda & Mechanics	
Dr. William R. Hamel, Forum Organizer	0820 – 0830
Keynote Presentations	
Perception and Sensing	
Professor Greg Hager, Johns Hopkins University, USA	
Presentation	0830 – 0900
Discussion	0900 – 0915
Intelligence, Reasoning, Knowledge	
Professor Lynne Parker, University of Tennessee, USA	
Presentation	0915 – 0945
Discussion	0945 – 1000
The Brain-Computer Interface	
Professor Ted Berger, University of Southern California, USA	

Presentation	1000 – 1030
Discussion	1030 – 1045
Break	***1045 – 1100***

Action

Dr. Antonio Bicchi, University of Pisa, Italy

Presentation	1100 – 1130
Discussion	1130 – 1145

Emerging MEMS and NEMS Technologies

Professor Brad Nelson, Switzerland, ETH Zurich

Presentation	1145 – 1215
Discussion	1215 – 1230
Lunch	***1230 – 1330***

Overview of the NSF/NASA/NIBIB International Assessment of Research and Development in Robotics

Professor Vijay Kumar, University of Pennsylvania, USA	1330 – 1415

Breakout Sessions

Assignments	1415 – 1700
Organization and Goals	
Dinner	1800 – 2000

Day 2, May 15, 2006 (Monday)

Continental Breakfast	*0730 – 0800*
Open Discussion	***0800 – 0830***

Keynote Presentations Continued

Cognitive Robotics

Dr. Raja Chatila, LAAS, France

Presentation	0830 – 0900
Discussion	0900 – 0915

Human Machine Interaction and Interfacing

Professor Shigeki Sugano, Waseda University, Japan

Presentation	0915 – 0945
Discussion	0945 – 1000

Continued Breakout Sessions	***1000 – 1200***
Lunch	***1200 – 1300***
Continued Breakout Sessions	***1300 – 1500***
Plenary Session	
Breakout Group Reports	***1500 – 1600***
General Discussions & Closing	***1600 – 1700***

APPENDIX III, BREAKOUT GROUP STRUCTURE & ASSIGNMENTS

	Breakout Groups							
Attendees	M&R Robotics	Robotics in Ext Envr	Service Robotics	P&S	A&M	HRI/C	Emerg Tcch	Intell & Cog
***Allison Okamura*[1]**	X						X	
Antonio Bicchi				X			X	
Bill Hamel		X			X			
Dick Volz				X		X		
Garie Fordyce								
***Geoff Pegman*[1]**			X					X
George Bekey	X						X	
Georges Giralt			X					X
Greg Hager				X		X		
Kevin Lynch			X					X
Lynne Parker			X					X
Michael Pardowitz			X					X
Mike Reischman		X			x			
Mung San Kim			X					X
***Ning Xi*[1]**				X		X		
Norman Caplan				X		X		
Ousamma Khatib				X		X		
Philippe Bidaud	X						X	
Raja Chatilla			X					X
Russ Taylor	X						X	
Shikegi Sugano				X		X		
Sukhan Lee			X					X
T.J. Tarn				X		X		
Ted Berger	X						X	
Toshi Fukuda	X						X	
Valery Gradetsky		X			X			
Vijay Kumar			X					X
Wayne Book		X			X			
Brad Nelson	X						X	
***Darwin Caldwell*[1]**		X			X			
Fernando Lizarralde								
Claudio Moriconi		X			X			
Steffen Knoop			X					X

[1]Facilitator/Recorder

APPENDIX IV, FUTURE WORKSHOP PROPOSALS

Breakout Groups

1. Medical and Rehabilitation Robotics, and Emerging Technologies
2. Robotics in Extreme Environments, and Action and Manipulation
3. Service Robotics, and Intelligence and Cognition
4. Perception and Sensing, and Human-Robot Interaction/Cooperation

Workshop Proposals

General Ideas for Workshops

3. <u>Some alternatives to the usual:</u>
    - Two-four week institute (like Telluride neuromorphic engineering workshop). People bring their labs. Develop new projects and work on them.
    - Include training component plus summer school for students.
    - End goal of the workshop is to create a new graduate-level course on X. Also, write a textbook.
4. <u>Possible workshop goals:</u>
    - Summarize/synthesize existing work
    - Identify barriers to research progress
    - Train new researchers (invite students to some aspects)
    - Solve barriers (work together to identify specific solutions)

BREAKOUT GROUP #1

Medical and Rehabilitation Robotics, and Emerging Technologies

Key potential workshop topics considered include:

- Biomechanical Tissue Modeling for Robot-Assisted Surgery and Simulation
- Safety and Quality in Biomedical Robotics
- NeuroRobotics for Rehabilitation, Prosthetics, and Orthotics
- Bio-inspired Design for Milli/Micro/Nano Robotics
- Micro/Nano Robot Architectures

Proposed Workshop 1, Biomechanical Tissue Modeling for Robot-Assisted Surgery and Simulation
Application: Medical/Rehab Robotics

Motivation: As robot-assisted surgery moves toward active assistance and autonomy, models of the environment (the patient) are necessary for safe and effective procedures. Also, training and practice for medical procedures requires accurate, patient-specific models with real-time graphic and haptic rendering. Such models can be used in the development and evaluation of tissue engineering.

Research challenges: Acquisition, development, and application of tool-tissue interaction models that will significantly enhance clinical practice.

Impact: Developing the "haptic human" (in addition "visible human") will substantially improve the accuracy, safety, and effectiveness of medical procedures. It may inspire new methods for diagnosis and treatment. Also, the workshop will provide a link between roboticists, biomechanicians, clinicians, and the simulation/modeling industry.

Workshop implementation recommendations:

Scope: Devices to acquire patient-specific tissue models in vivo and non-invasively (e.g., elastography), Development of models that are computationally efficient and characterize complex tool-tissue interactions such as cutting, The application of models in robot-assisted surgery and medical training

Participants: Researchers in medical robotics, biomechanics, haptics. clinicians. medical robotics, and simulation industry.

Proposed Workshop 2, Safety and Quality in Biomedical Robotics
Applications: Medical/Rehab robotics diagnosis

Motivations : robotics may improve safety, security and quality of patient care medical devices must guarantee a high level of safety. Increase gesture comfort, precision, dexterity, dependability

Research challenges: To create systems that are extremely reliable and fault-tolerant in terms of hardware, software, and human-machine interface. Evaluation methods are needed.

Impact: Identify coupling physic principles candidate for micro robots design. Define a multi-physic simulation environment for virtual prototyping and manipulation/assembly analysis.

Workshop implementation recommendations:

Scope: redundancy in control and sensing, design of intrinsically safe system, tradeoff between, reliability and safety, robust sensor based control, emergency procedures, computer assisted surgery virtual reality and augmented perception for gesture control, force/vision feedback and passivity in telerobotic systems, active filtering of physiological motions

Participants: Surgeons, medical robotics researchers and industry, other clinicians

Proposed Workshop 3, NeuroRobotics for Rehabilition, Prosthetics, and Orthotics
Application: Medical/Rehab robotics

Motivation: Recent developments in the use of robots for neuromuscular system rehabilitation and prosthetics are emphasizing the importance of brain plasticity, i.e., systematic movement of the limbs can produce measurable changes on cortical and sub-cortical motor areas. The recently announced DARPA program in upper extremity prosthetics will build on current work in direct neural stimulation and motor learning, including haptic feedback.

Research challenges: Development of methods for feedback of haptic information; new methods of direct brain control of robotics devices with multiple degrees of freedom

Impact: Breakthroughs could lead to major applications of robotics for rehabilitation of people following strokes or injury, as well as development of new prosthetic and orthotic systems

Workshop implementation recommendations:

Scope: The workshop should cover a broad range of topics related to rehabilitation robotics, prosthetics, and orthotics, including recent models of neuromuscular system, brain plasticity, physical therapy and training systems, as well as robot design that emphasizes light weight, compatibility with human anatomy and ease of use.

Participants: The workshop should include researchers and practitioners in robot system design, neuroscience, sensory system physiology and physical therapy, and prosthetics

Proposed Workshop 4, Bio-inspired Design for Milli/Micro/Nano Robotics
Application: Emerging Technologies

Motivation: Biology provides design inspiration for sensors, actuators, navigation, and locomotion techniques that are appropriate for small-scale devices.

Research challenges: Selection and implementation of bio-inspired designs and control strategies that will enable the next generation of small-scale robots for surveillance, inspection, and medicine.

Impact: The design of such devices may revolutionize the way in which we diagnosis, monitor, and treat problems in the areas of security and medicine. Close collaboration with biologists and fluid dynamicists will yield exciting new design ideas.

Workshop implementation recommendations:

Scope:

- Bio-inspired designs for sensing and actuation mechanisms, control and behavior
- Novel fabrication approaches and self-assembled devices
- Locomotion techniques that are appropriate for small scales, used by organisms for swimming and flying
- Applications of milli/micro/nano robotics (surveillance, inspection, and medicine)

Participants: Researchers in milli/micro/nano robotics, MEMS/NEMS, medical robotics, biology, fluid dynamics. Clinicians, medical robotics industry, military.

Proposed Workshop 5, Micro/Nano Robot Architectures
Application: Emerging Technologies

Motivation: Very small robotic devices can operate in unique and formerly inaccessible environments. At the micro/nano scale, we must reconsider the design of hardware and software architectures.

Research challenges: Development of a systems perspective on autonomous micro/nano robotic devices.

Impact: Identify modeling principles for micro robot design. Define a multiphysics-based simulation environment for virtual prototyping and manipulation/assembly analysis.

Workshop implementation recommendations**:**

Topics: Active materials, fabrication processes for hybrid systems, virtual prototyping and performance analysis, 3D compliant and resonant structures, distributed actuation and sensing, active fiber mechanics, power/energetic sources, swarms, applications (Micro-machines, Medical micro-devices, Material Science, Biology, security, etc.)

Scope: State of the art, the tendency in the research, application of micro robotics and micro technologies and their evolution to nanotechnologies and nano devices, as well as integration issues are the major scopes of the workshop.

Participants: Roboticists, physicists, material science engineers, MEMS/NEMS researchers

BREAKOUT GROUP #2

Robotics in Extreme Environments, and Action and Manipulation

Extreme environments include as a minimum:

- Space,
- Nuclear,
- Subsea,
- EOD/IED,
- Chemical,
- Biohazard,
- Demining,
- Mining,
- Firefighting,
- Rescue.

Proposed Workshop 6, Shared Control for Robots in Hazardous Environments
Application: Robots for Extreme Environment

Motivation:
Robots operating in life threatening environments display a range of control from full tele-operation to high levels of task autonomy. However, in almost all instances there is a human in the loop. Depending of the position of the robot on this continuum, designers may ask:

- How can greater autonomy augment and enhance the human operation?
- If the robot fails/stalls in its task how can a human operator "restart" operations?

Research Challenges:
In extreme environments how does the system transfer modes from one state to another and in particular how can you overlay faults and failures within design concept.

How does an autonomous robot know that it cannot do a task and how does it ask for help once it has reach a "dangerous" irresolvable position.

Impact: Breakthroughs in shared decision-making and shared control could have a significant impact on the capacity and efficiency of teleoperational tasks.

Workshop Implementation Recommendations:
Issues

- Is intelligence a disadvantage with respect to autonomy?
- For anthropomorphic robots, teleoperation may be relatively easy but when not anthropomorphic manual operation may be a big problem.
- What happens when assumptions associated with design process do not work in the operational environment?
- There were issues relating to the seamless transfer between different points on the continuum.

Participants: AI, tele-operation users, Ergonomists, Hazardous environment operators

Proposed Workshop 7, Robot Energetics

Application: Robots in Extreme Environments/ Action and Manipulation

Motivation: Mobile systems operating in extreme environments must be either self powered or powered through complex tether systems. For system power autonomy there is a need to address fundamental issues in power generation, power storage and power utilization (actuation). In some of these areas particularly power generation and storage there was felt to be a lack of expertise in the robotic community and drawing in new speakers could be very illuminating.

Research Challenges: Development of safe, reliable, high density

- power generation systems
- power storage systems
- power utilization systems (new and improved actuation technology)
- and techniques for rapid recharging and refueling.

Impact: Breakthroughs should lead to a new class of robot (mobile platforms, manipulators and tools) with freedom to roam over vastly extended ranges and durations.

Workshop Implementations and Recommendations:

Scope: Workshop should give careful consideration to:

- Entire energy consumption and supply cycle from storage media to conversion necessary for robot motion and other fundamental operations such as lighting.
- "Fuel" limitations inherent to various application domains should be identified.

Participants: Chemists, physicists, and roboticists

Proposed Workshop 8, Robotic IED Detection
Application: Robotics in Extreme Environment

Motivation:
Given the current international security situations there is an increasing need to be able to address all aspects of IED threats, ranging from roadside devices to suicide missions. Particular emphasis should be placed on robust and timely detection.

Research challenges:
- Development of new sensor technologies,
- Sensing at a distance,
- Interaction between chemists, roboticists and user community.

Impact: The ability to detect IED will have immense impact of security and public confidence.

Workshop implementation recommendations:
Scope: Workshop should give careful consideration to:
- Sensor technology
- Mobility
- Survivability
- User needs

Participants: Chemists, Sensor technologists, roboticists, IED/EOD; bring together scientists working on fundamental sensing mechanisms with roboticists.

Proposed Workshop 9, Mission Driven Reliable Robot Design
Application: Extreme/Action and Manipulation

Motivation: For many if not most tasks in extreme environments the completion of the mission is not only desirable but essential. In these instances there are significant issues with failure both in terms of the cost to the robot but perhaps more importantly in failure to complete the mission. Links closely with the area of AI.

Research challenges:

- Many modes of failure,
- Cost of failures how is this to be evaluated to inform the design
- Cost of robot or cost of the program/mission,
- Software reliability
- If the robot is to detect the problem there are issues of perception and forecasting.

Impact: A breakthrough could lead to new techniques to manage and mitigate the consequence of failure in areas were there is no alternate human form of intervention.

Workshop implementation recommendations:
Scope: Workshop should give careful consideration to:

- Design to failure rate,
- Robotic systems that are self and environmental monitoring recognizing the inability to complete tasks and recognizing when the system is approaching operational limits and consequently knowing that the risk of failures is related to proximity to these limits.
- Input from social scientists on the acceptability of non-accidents (minor, major). Children play with dogs but dogs bite. What level of safe interaction is acceptable for different environments.
- Design Rules - How to incorporate into the design process reliability issues and relating this to the probability of achieving a task.
- Redundancy, Fault tolerance, Intrinsically safe operation.
- Integrating reliability engineering inside the project.

Participants: Representatives might be expected from all areas having and interest in extreme environment operation: Space, Nuclear, Subsea, Military (IED/EOD, demining, fighting vehicles) etc. AI, social scientists, design engineers.

BREAKOUT GROUP #3

Service Robotics, and Intelligence and Cognition
Proposed Workshop 10, Robot Learning Systems
Application: Advanced robots with particular emphasis on personal robots

Motivation:
- Learning new environments, tasks & behaviors
- Adaptation
- Robots can be programmed with basic concepts and approaches.
- Robots can learn to apply these general concepts to specific applications. The general concepts can also be grown / expanded through these interactions with the environment thus growing the capabilities and knowledge base.
- Practical applications and in human environments– Difficult / impossible to pre-program all contingencies. Therefore they need to learn or be taught new environments and/or tasks.

Research challenges:
- Efficient Algorithms.
- Saliency
- Generalization
- Autonomous Learning

Impact: Central to efficient operation of advanced, flexible systems

Workshop implementation recommendations

Scope*:*
- Learning through -Reinforcement
- Experience
- Analogy
- Instruction
- Constructivism
- Lifelong Learning
- Accommodation to human user skills and preferences

The workshop will favor sensor-based learning of new skills and knowledge. (Excludes mapping)

Participants*:* Robot community, educators, AI community, psychologists, neuroscientists

Proposed Workshop 11, Human-Robot-Human (HRH) Interaction: Tools for Rehabilitation and Training
Application: Rehabilitation and Training

Motivation: Physical therapists need tools to help them in rehabilitation of patients. Robots (assist devices) mediating the interaction between therapist and patient can relieve the therapist of exerting large, stressful forces and can record data regarding patient's performance. This data will impact the course of future training. The robot is also capable of guiding a patient through precise motions that might be difficult for the therapist, and of making itself transparent (i.e., simply directly coupling the human to the robot without any modification of forces) as the patient improves in performance. A robot for HRH keeps the human's intelligence and judgment in the loop and allows the therapist to use high-bandwidth force feedback during the training, rather than just observing and interacting with the patient at low bandwidth (as with a typical rehabilitation robot).

Research challenges:

- Developing intent sensors (robot decodes what humans are trying to do). This is relevant for just human-robot interaction, too. EMG's, forces, neural signals, fMRI, etc.

- In human-human cooperation, we have continuous exchange of information by forces, and perhaps visual and audio cues. Just looking at force communications, how do humans communicate intent and result in a stable cooperative control system? How do we preserve this when we insert a robot or assist device between people, while allowing the robot to amplify forces, displacements, and perform other transformations of forces and motions?

- Development of rehabilitation protocols and tools to assist with rehabilitation and training.

Workshop implementation recommendations

Impact*:* Providing increased functionality to injured people through improved rehabilitation, while protecting rehab therapists from injury. Also potential for training of normal subjects in difficult or dangerous motor control tasks.

Participants*:* Rehabilitation therapists, robotics engineers, experts in human biomechanics and motor control, neuroscientists

Proposed Workshop 12, Self-Organizing Systems
Application: Long-range: self-assembling systems

Motivation: Computer scientists, chemists, biologists, and roboticists are studying different models of self-assembly, information propagation in collections of agents, and distributed intelligence, all to support self-organization. Each community brings a different set of constraints to shape their thinking on the problem. They will benefit significantly from learning the others' methods and language.

This area has huge potential applications

Research challenges:

- Technologies to bring the computation assumed of the individual agents in models used in robotics and computer science to smaller size scales.

- Identifying the minimum computation and communication necessary to achieve certain classes of self-organization.

- Identifying computations and communication that can be performed by simple chemical, van der Waals, hydrophilic/phobic, etc., and understanding / emulating small scale physical effects at larger scales or within information processing systems.

- Determining effective and optimal component use within heterogeneous systems

Workshop implementation recommendations:

Impact*:* There is the potential for discovering new and potential methods of building, programming and using self-adapting robots, multiple robot systems and heterogeneous robot swarms

Participants*:* Computer scientists and mathematicians ([toy] models of information propagation and self-assembly, and decentralized algorithms), chemists and biologists who look at physical phenomena that can lead to self-assembly, roboticists working on models and instantiations of self-organizing physical systems (cellular models, robot molecules, etc.) Swarm robotics participants

Proposed Workshop 13, Cognitive Robot Architectures
Application: All Cognitive Robots

Motivation: Advanced cognitive robots will have capabilities of perception, reasoning, understanding, planning, action and communication. These different capabilities need to be developed within a consistent framework and utilise compatible representations, i.e. a robot architecture. Such architectures can either be ad hoc or developed in a systematic manner. This series of workshops aims to examine the basis and implications of such systematically developed robot architectures.

Research challenges:

- Consistent / optimized representation systems;
- Modular sub-systems;
- Effective grounding of cognitive robot functionality in effective real-world actions;
- Efficient representational systems;
- Effective use of large data / knowledge sources

Impact: Effective cognitive robot architectures are an essential underpinning of advanced robot. A general consensus on a limited number of architectural approaches and representation schemes would more easily support synergistic cooperation of different research groups and thus support the development of more complete cognitive robots.

Workshop implementation recommendations:

Scope:

- Architectures
- Representation systems
- Management of knowledge bases
- Structure & Theory of Mind(This could be a separate one-off workshop)

Participants: Robot community, computer scientists, cognitive psychologists, neuroscientists

Proposed Workshop 14, Complex robot interaction with the real world
Application: Advanced robots with particular emphasis on personal robots

Motivation: Dealing with everyday objects in a human-centered environment requires robots to handle and interact with many unknown objects. This in turn requires reasoning about their use and utility as well as being able to grasp arbitrary objects safely and securely.

Research challenges:

- Haptic integration
- Multi-modal sensor integration
- Grasp planning
- Object reasoning (e.g. function from shape, utility from context)
- Knowledge acquisition (e.g. by discovery or by being taught)
- Knowledge application (using abstract or generalized strategies in concrete situations)

Impact: General personal robots that can handle and reason about real-world objects will be able to operate across a much wider range of tasks and operate with novice users.

Workshop implementation recommendations:

Scope:

- Using and integrating Haptic information
- Grasp Planning
- Object reasoning

Participants*:* Robot community, Ergonomists, Consumer electronics & white goods industries

Proposed Workshop 15, Ambient and Embedded Intelligence
Application: Domestic and office robots

Motivation: For advanced robots to be effective and economically viable in future applications the various perception, understanding, reasoning and planning systems will have to run on embedded computers with relatively sparse resources. Furthermore, to take full advantages of the knowledge and information offered by the ubiquitous computing future, these robots will need to exchange data and knowledge efficiently and effectively with ambient environments.

Research challenges:
- Efficient algorithms
- Effective and compact representation systems
- Data saliency and learning
- Knowledge exchange – Identification, negotiation, retention & updating

Impact: Needed for the widespread use of smaller cognitive robots in domestic environments.

Workshop implementation recommendations:
Scope:
- Embedded cognitive computing
- Knowledge sharing in an ambient environment
- Knowledge representation
- Algorithms
- Operation in tagged and untagged environments

Participants: Robot community, computer scientists, consumer electronics and white goods industry.

Proposed Workshop 16, Social & Personal Robots
Application: Social Robots

Motivation: For robots to be accepted as social companions and co-workers they need to both act intelligently in their interaction with the world, but also interact effectively with people and each other. To interact with users requires the robots to understand user's explicit and implicit requests and needs in context and to adapt

Research challenges:

- Natural language communication
- Gesture recognition
- Emotion recognition
- Emotional display
- User preference learning and adaptation
- Intent identification

Impact: The ability for cognitive robots to act appropriately in a social setting and to understand (complex) social interaction will be needed for the wider acceptance of robots as personal assistants or as co-workers, rather than as a complex toy or gadget.

Workshop implementation recommendations:
Scope:

- Natural language communication
- Non-verbal communication
- Cooperation with non-controlled agents
- Emotion recognition & display
- Adaptive user interfaces
- Cultural interaction preferences
- Learning in a social context

Participants: Robot community, Computer scientists, social psychologists

BREAKOUT GROUP #4

Perception and Sensing, and Human-Robot Interaction/Cooperation
Proposed Workshop 17, Human/Robot Interfacing at Neural Level
Application: Human/Robot Interaction and Cooperation

Motivation: The current technologies for human and robot to interface and interact remain at the level of mechanical, visual, and audio. It is desirable to directly interface a robotic system with human at cognitive level. It will significantly improve to ability for human to control and cooperate with the robotic system. Furthermore, it will also enhance the human capabilities, such as mobility and manipulability.

Research challenges: Develop an efficient and human friendly interfacing technology to communicate between a human and a robot at neural level.

Impact: Breakthrough could lead to a new technology and applications of robots. It will impact in the areas of biomedical and human/machine interface.

Workshop implementation recommendations:
Scope: Workshop should give careful consideration to:

- Biocompatibility, efficiency and effectiveness of the interface;
- New planning and control methods for robot action based on the human neural signals

Participants: Representatives from neural science, robotics, human/machine interface, and cognitive science should be considered.

Proposed Workshop 18, Robot-Assisted Living
Application: Service Robotics

Motivation: The last decades have seen a strong trend toward increasing level of home automation. This trend will be accentuated as the population ages and the need for increased physical assistance and monitoring in the household rises. To capitalize on this opportunity, there is a need to explore how sensing and robotic technologies can be integrated into the home environment in a useful and safe manner. This in turn can be used to drive the research agenda in this area as well as engaging the relevant industries.

Research challenges: Sensing and sensor fusion coupled with; human-robot interfaces; robotics in unstructured environments.

Impact: Research breakthroughs in this area would be broadly relevant to many areas of robotics. New application ideas could have significant impact on the societal relevance (and hence visibility) of the field.

Workshop implementation recommendations:
Scope: The workshop should be organized to generate new specific ideas of how robotic systems could be integrated at both a component and a systems level. Topics should include specific devices (e.g. intelligent appliances or transport/assistance for the disabled) to issues such as system architecture and integration.

Participants: Representatives from all topical areas including sensing (particularly vision), mechatronics, and manipulation should be included. Relevant industries (e.g. iRobot, GE, Siemens, Toyota) should be invited and included.

Proposed Workshop 19, Human-Robot-Environment Integration
Application: Human-Robot Interaction and Interface

Motivation: Intelligent function and ability of conventional robots are so limited. `Assistance by the environment that has information about map, positioning, task, service contents, and security may be effective for the robot motion generation and its control. As robots can easily get the seamless map of rooms and towns, the position of humans, furniture and itself, and task performance procedure etc., even if robots do not have sufficient sensing and intelligent ability, robots can perform various tasks with human cooperatively.

Research challenges: Design and development of the environment system which involves positioning, task and service information. Positioning method using RFID tags and indoor GPS system. Development of portable devices.

Impact: It may become easy to put robots to practical use in welfare facilities and homes without high level of intelligence.

Workshop implementation recommendations:
Scope: Workshop should give careful consideration to:

- How to collaborate with AI researchers.

Participants: Representatives from the field of Architecture, Sociology and Industrial Management (ex. distribution) which are deeply related to the future life style design should be considered.

Proposed Workshop 20, Sensor-Based Manipulation
Application: Perception and HRI

Motivation:

There is a great need for the integration of perception with manipulation. While not much of effort has been pursued in this area,
Significant advances have been made in sensor-based navigation for mobile robots. These developments provide a good stimulus and good tools to undertake similar work in manipulation.

Research challenges:
Robust perception, tactile SLAM, strategies for grasping, sensor-based compliant motion strategies

Impact:

Robust robotic manipulation capabilities in unstructured environments could lead to applications in many industries (handling, packaging) and in service and field robotics.

Workshop implementation recommendations:

It is important for the workshop to bring the needed multidisciplinary expertise in perception and manipulation. Contributions should be solicited in the areas of grasping, dexterous manipulation, modeling from range data and from vision, tactile sensing and estimation, and compliant motion strategies – with emphasis on experimental validation and on developments of quantitative benchmarks to drive the field forward.

Proposed Workshop 21, Haptics - Modeling, Sensing, Display
Application: Perception and HRI

Motivation: Haptic interfaces are devices that allow human-machine interaction through force and touch. Although touch is perhaps the most direct and convincing type of interaction with remote and/or virtual environments, its understanding and the related sensing and display technologies still pose many challenges. One particular aspect of research in haptics is that it involves the need for truly interdisciplinary expertise between human sciences (psychology, neurophysiology, biomechanics) and engineering of the sensing and display devices used to build the interfaces: the former providing the basic understanding for the development of the latter, which in turn is the unique enabler for the former. The workshop would address all aspects related to haptic interaction - from the basic scientific underpinnings, to the technological developments, to the different realizations and applications.

Research challenges: A better understanding of the sense of touch, comparable to what we have about vision: what are the equivalents of vision primitives, invariants, and features in touch? How can we measure those in tactile sensor data, and how can they be represented and replicated in displays, to build a new generation of accurate, lightweight, free hand, wearable interface that can display both tactile and kinesthetic information?

Impact: Breakthroughs could lead to the development of a haptic interface capable of rendering complete tactile and force information, which is acceptable to the user in terms of encumbrance and ergonomics, and provides a convincing feeling of "being in touch" with the remote/virtual environment.

Workshop implementation recommendations: It is crucial that the workshop gathers the necessary interdisciplinary expertise. Accordingly, papers should be solicited in three main areas:

- Science of Haptic Perception: psychophysics, neurophysiology, biomechanics, etc.
- Technology of Haptic Interfaces: device design and control
- Applications of Haptic Interfaces to Virtual Environments and
- Teleoperation Systems: training, medicine, scientific discovery, entertainment, exploration, remote/hazardous manipulation, etc.